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TECHNICAL MEMORANDUM NO. TM - 510

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AURAL DETECTION OF MACHINERY TONES IN SHIP NOISE.

INTRODUCTION

This memorandum describes a new method for the detection and frequency measurement of machinery tones in ship noise using only aural analysis techniques. The technique described has been subjected to preliminary tests the results of which show conclusively the high operational value of the method. It is anticipated that the detailed results of these and further tests will be published formally at a later date. In the meantime this memorandum should serve to acquaint particularly interested persons with the power of this new technique.

The Problem: Passive sonar analysts, particularly submarine sonarmen, have been aware for many years that strong single-frequency tonal components are a common feature of ship noise at the audio frequencies. Recently developed methods of passive sonar target classification such as those reported in references (a) and (b) depend strongly upon the detection and accurate measurement of the frequency of such tones. The detection and frequency measurement of such tones has heretofore depended upon the availability of extended-band Lofar equipment capable of covering the frequency range up to at least 1200 c/s. Such equipment is not yet available in any operational form and as a consequence application of these classification techniques has remained essentially a Laboratory procedure.

Recognition of these facts led to institution of a program to attempt to develop a purely aural technique by which the necessary measurements could

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be made with sufficient accuracy to allow application of the new classification methods during the period until appropriate spectrum analysis equipment becomes generally available in the fleet. The technique reported here has evolved slowly after several other methods were tried and found wanting. Probably the first method to be tried operationally was through the use of adjustable high-pass and low-pass filters This method, like most others, requires the operator/analyst to first detect the presence of a tone in the broad band signal. The cut-off frequency of the high-pass filter is then lowered until the amplitude of the tone drops sharply and the cut-off frequency is read from the dial. The high-pass filter is then backed off and cut-off frequency of the low-pass filter is gradually raised until the tone again drops out and the dial reading is made. The mean of the two dial readings is then taken as the frequency of the tone. Most submarines are now equipped with the necessary filters to make measurements in this fashion and the method may be considered standard in the fleet. Measurements made in this manner are highly inaccurate and tones with very high signal-to-noise ratios are required before the method can be applied.

An early attempt to improve the accuracy of frequency measurements was through the use of an adjustable narrow band rejection filter, or notch filter, which could be adjusted by the analyst until the amplitude of the tone was a minimum and the frequency could then be read from the filter dial. This method was reported in reference (c). The accuracy of frequency measurements was improved somewhat by this method but it otherwise suffered from the same deficiencies as the double cut-off method.

Proposed Solution: The new technique has been designed to take full advantage of the known characteristics and capabilities of the human ear. It

makes use of a band of frequencies in which the human ear is most sensitive, its response is most uniform and the critical bands of the ear are narrow and uniform. Full advantage is taken of the ear's high sensitivity in the recognition of low frequency beats. The equipment required is restricted to that normally available in present submarine sonar rooms; a three-speed magnetic tape recorder with a short loop attachment, an octave band filter set to pass 600 to 1200 c/s, an audio oscillator tunable from 600 to 1200 c/s and, for best results, a frequency counter reading to the nearest cycle per second in the 600-1200 c/s range. A block diagram of the equipment set-up is shown in Figure 1.

It is assumed that most of the tones of interest will lie in the band from 300 to 2400 c/s. In the analysis, however, the band being examined at any one instant is restricted to 600-1200 c/s. This allows the analyst to concentrate his attention on a single octave at a time and drastically reduces problems arising from auditory masking and aural harmonics. The analyst's operating instructions are as follows.

The signal to be analyzed is recorded on the short tape loop at the middle tape speed, normally 7,1/2 ips. On playback the signal is fed through an octave band filter so that the operator hears only the band from 600 to 1200 c/s. In practice this filter should be set to pass frequencies from about 500 to 1300 c/s so that no confusion will result near the cut-off of the filter. Starting at the lowest frequency, (600 c/s) the oscillator level is set to where the tone can just be heard clearly and the frequency of the oscillator is then slowly increased. The analyst should listen carefully to the oscillator tone only and not try to hear the noise or any tones which may be present in the noise. The oscillator output level should be continuously adjusted throughout

to keep the oscillator clearly audible above the noise. If the analyst fails to concentrate solely on the oscillator tone he will tend to report spurious tones due to the beating effect of the background cavitation noise. If there is a tone present in the noise the oscillator tone will start to beat as its frequency approaches the frequency of the unknown tone. Still listening to the oscillator tone the analyst may then establish a very accurate "zero-beat" point. The frequency of the unknown tone may then be read from the oscillator dial. (With normal oscillator dials and calibrations the greatest error will arise in the process of reading the dial. For this reason the results of the measurements can be greatly improved by using the frequency counter, as shown in Figure 1, to read the oscillator frequency.) This process is then continued tone-by-tone moving slowly across the frequency range to 1200 c/s. It should be emphasized here that by this method the analyst will detect tones which he cannot detect aurally by any other means, the process must be followed even though there are no apparent tones present in the band.

In the target classification process it is imperative that tonal frequencies be measured with the greatest possible accuracy and that as many tones as possible are measured. It is equally important however, that only real tones be measured and that the "false-alarm" rate be kept to a minimum. If the operator records the frequency readings only for those tones which can definitely be made to beat and for which the beat rate can be changed by jockeying the oscillator dial he will restrict his readings only to real tones and will, with a little practice, be able to detect tones which he cannot otherwise hear.

Having completed the search from 600 to 1200 c/s the analyst should slow the playback speed to 1/2. The frequencies originally falling in the range from 1200 to 2400 c/s will now fall into the range of the fixed filter and the

process is repeated. Frequencies read from the oscillator or counter will now be 1/2 of the original frequencies and the values must be doubled before they are used for computation. When this frequency band has been examined the playback speed is changed to the fastest setting which should be twice the original record speed. Now the band of frequencies which was origanlly 300 to 600 c/s will appear in the filter band and the process is repeated once more. Frequencies read from the oscillator will now be double the true frequency and must be divided by 2 before being used for computation.

Testing the Technique: The method described above showed excellent promise when tried in the Laboratory but it was decided to subject the technique to at least a preliminary test before submitting it for operational use. Six test samples were chosen from previously recorded sounds from various types of geared-turbinepowered ships. The samples varied in difficulty and in the number of tones present and care was taken to ensure that somewhere in the test there was at least one tone in each octave.

Plans were made to give the test to three different groups of people. The first group was composed of twelve experienced, submarine sonarmen who were provided only with the adjustable band-pass filters normally available on board the submarines and were instructed to determine the tonal frequencies by whatever method they were used to using. The secoud group was made up of ten experienced sonarmen of varying backgrounds who were provided with an oscillator and frequency counter and were given instructions essentially the same as those given above. The third group was made up of ten seamen with no previous sonar experience of any kind who also used the oscillator-beat method of tone finding.

In order to simplify the test procedure, especially for the inexperienced

group, the test recording was made up in two different forms. In the first form, used only by Group I, the samples were recorded consecutively through a 300 to 2400 c/s band-pass filter. Each sample was six minutes long except the last which was only three minutes. In the second form, used by Groups II and III, the problem of speed changing on the playback was eliminated by recording each sample for two minutes at each of three speeds so that the analyst had two minutes to work in each octave. The last sample was again only three minutes in total length. At the beginning of this reel, voice instructions for the test were recorded together with a couple of strong tones to be used for practice in the technique before starting the test. While giving the test to Group III, the inexperienced seamen, the test instructor controlled the level of the oscillator tone. The sonarmen in Group II controlled their own oscillator levels.

Figure 2 shows Lofar records of the six test samples. There is no expectation that any aural technique will compete in tone detection ability with the Lofar and these records are shown primarily for illustrative purposes. Standard or "correct" frequencies for tones found aurally in the test are taken from the Lofar records. Casual examination of Figure 2 will show that each sample contains several tones and that there is at least one strong tone in each sample. It also shows that some of the test samples should have been more carefully chosen since there are definite frequency shifts within the length of the samples, particularly in samples 2 and 6. Despite some of these obvious faults the test samples were found satisfactory for this preliminary test.

Test Results: The purposes of the preliminary test were twofold. The primary purpose was to compare tone finding and measurement capabilities of the

two methods of aural analysis. The second was to get some indication of whether the new method could be applied by inexperienced people and to compare their results with those of the other two groups. There are many questions concerning learning and experience in the use of the oscillator-beat technique and ultimate ability to detect weaker and weaker tones but no attempt was made to answer these questions at this time. Our principal concern was to determine whether the new technique yielded better results than present operational methods.

A cursory examination of Figure 2 shows the presence of nine strong tones which appear to be materially stronger than any of the others. These nine tones were selected for this preliminary examination and are marked A through I in Figure 2. The results in relation to these nine tones are shown in Table 1. For each tone and each Group the table shows (1) the number of people who detected the tone, (2) the mean frequency measured by those who detected the tone, and (3) the standard deviation of measured frequencies.

In every case the persons being tested listed tones which could not be reasonably related to any signals shown on the Lofar records. For each of the nine tones then, some arbitrary method had to be adopted for determining whether or not the tone had been detected. For Groups II and III this arbitrary limit was taken as ± 10 c/s on the grounds that beats cannot usually be heard if they exceed this frequency. The accuracy of frequency measurement for Group I was expected to be much poorer than for the other groups so, since the filter scale accuracy is proportional to frequency, an arbitrary limit of ± 5 percent was selected.

Summary of the data presented in Table 1 is fortunately very straightforward. The 12 men in Group I had the opportunity to detect 108 tones. Only 13 were detected and in no case did more than 3 men detect any one tone. Average frequency

errors were high and standard deviations, where computable, were large. The measurements would be useless for application to target classification.

The 10 men in Group II, all experienced sonarmen, had 90 opportunities to detect these tones and did so in 66 cases. Three of the nine tones were detected by all ten men. Average frequencies for the tones were very close to our best measurement in all cases but one and standard deviations were very low. These last results are controlled to a certain extent by the 10 c/s limits placed on allowable errors but even with this limitation the actual measurements lie well inside the arbitrary limit. It is interesting to note that the one tone "C" for which this group did poorly was the first tone to be measured in nearly every case. For this one sample tone we were convinced that each of the nine men had in fact found the tone and the 10 c/s limits were relaxed to include all reasonable measurements. Had the 10 c/s limit been strictly imposed only four men would have been adjudged to have found the signal. It appears that perhaps learning played a part even in the short duration of this test.

The 10 inexperienced sonarmen in Group III also had 90 opportunities to detect the tones and did so in only 18 cases. For those tones which were found the accuracy of frequency measurement and small standard deviations inherent in the system are reflected in Table 1. All reasonable figures shown for tone "C" were again included in the table.

Conclusions: **In the hands of experienced sonarmen the technique described above is a powerful and accurate tool for determination of the frequencies of strong machinery tones in ship noise. Its use operationally in submarines promises far better results than present methods and in particular, results should be sufficiently accurate for use in modern target classification techniques.**

Comparison of results with experienced sonarmen and inexperienced seamen indicates that training and experience are a factor in use of the method. However, since only half of the men in Group II had previous passive sonar experience it suggests that familiarity with electronic equipment and with discriminative listening in general may be at least as important as direct experience in tone finding.

Although not demonstrated in this test it is strongly suspected that the method can be quickly learned even by the most inexperienced person and further that additional experience in use of this technique would quickly extend the experienced sonarman's ability to detect weaker tones while simultaneously reducing his false alarm rate of detection of non-existent tones and reducing analysis time.

Planning: Further testing of the capabilities inherent in this technique are planned. It is not believed that the technique, as presented, is necessarily the optimum method of aural measurement of tones in noise and further efforts will be made to improve the method. Several possible improvements which have already suggested themselves will be tried and tested. It is anticipated that a formal report will be issued upon completion of further tests and technique improvements.

<u>REFERENCES</u>

(a) USNEL Report 1010, "A Method for Passive Sonar Target Classification," by R. Halley, 3 January 1961 (S).

(b) COMSUBPAC INSTRUCTION 003522.12 of 10 May 1961.

(c) NEL ltr NS 713-225 (NEL L2-10) ser 2320-038 of 29 Sep 1959 w/encl (1) "The Use of a Variable Narrow-band Rejection Filter in Aural Analysis."

TABLE I

	Signal letter Frequency c/s	A 700	B 1280	C 1620	D 2140	E 372	F 425	G 990	H 2000	I 450
Group I	No. detected Mean freq. Std. Deviation	1 720 -	2 1215 -	3 1650 42.5	2 2172 12	3 375 26	1 450 -	0 - -	0 - -	1 450 -
Group II	No. detected Mean freq. Std. Deviation	2 701 1.6	3 1282 2.8	9 1624 20	10 2137 3.2	10 373 2.5	10 430 2.5	9 990 4.4	5 2000 11.9	8 447 4.2
Group III	No. detected Mean freq. Std. Deviation	0 - -	1 1276 -	2 1631 51	5 2140 2.0	0 - -	8 429 2.3	0 - -	0 - -	2 456 5.0

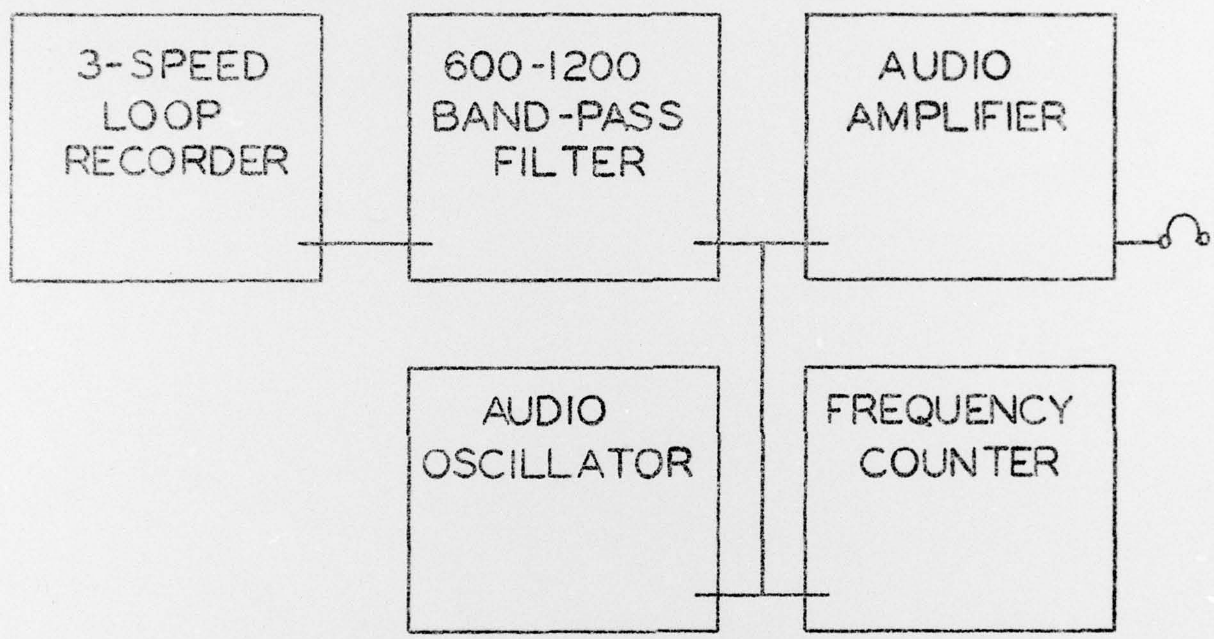
3-SPEED LOOP RECORDER
600-1200 BAND-PASS FILTER
AUDIO AMPLIFIER
AUDIO OSCILLATOR
FREQUENCY COUNTER

FIGURE 1

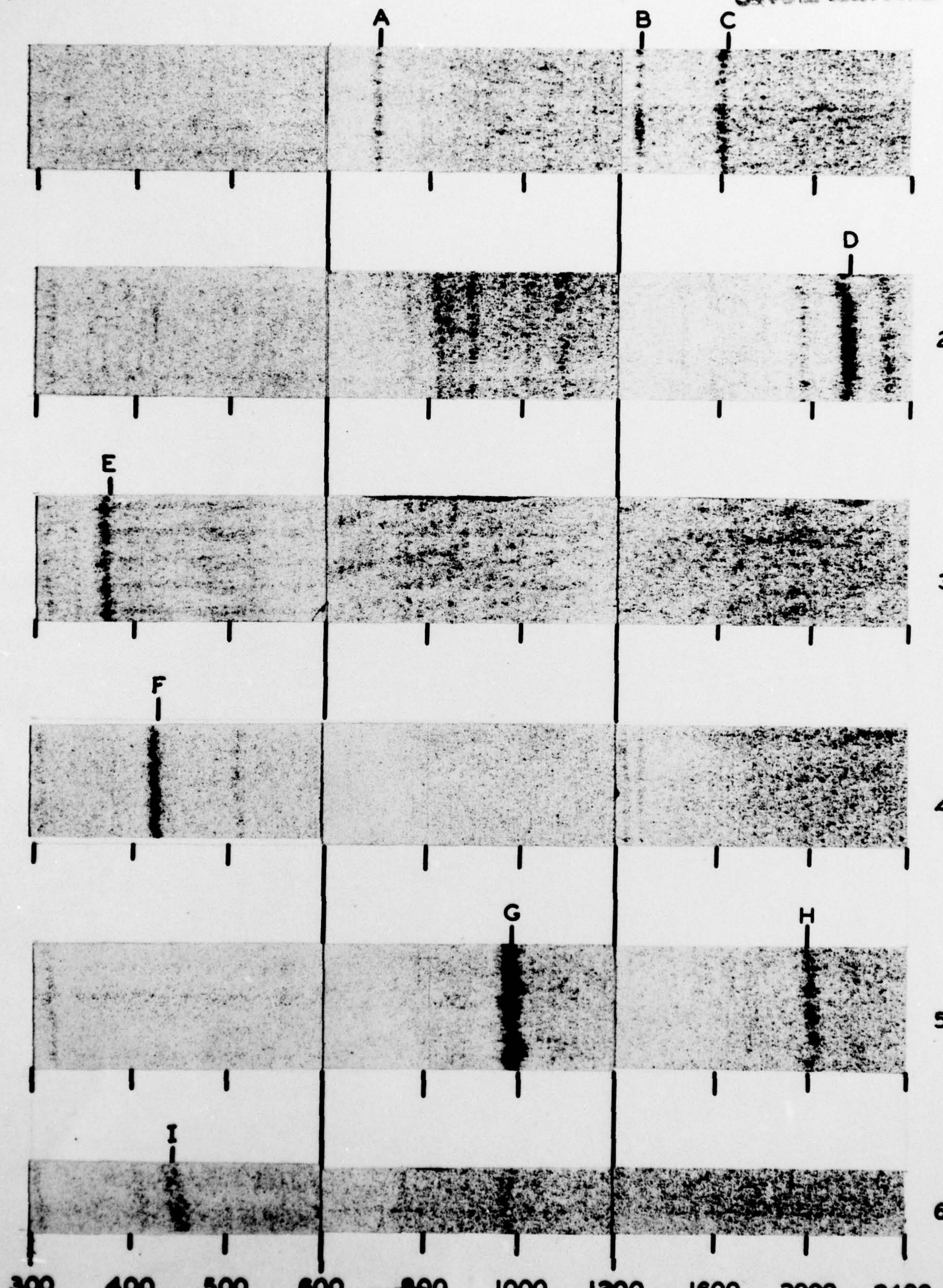
A
B
C
D
E
F
G
H
I
1
2
3
4
5
6
300
400
500
600
800
1000
1200
1600
2000
2400

FIGURE 2